

## FORGE WELDING METHOD

Background of the invention

The invention relates to a method for joining pipe ends by forge welding.

5 Forge welding involves circumferential heating of the pipe ends that are to be joined and subsequently pressing the pipe ends together to form a metallurgical bond.

A large variety of heating technologies may be used to make the pipe ends hot enough such that the metallurgical bond can be made. The heating techniques  
10 may involve electric, electromagnetic, induction, infrared, sparking and/or friction heating or combinations of these and other heating methods.

When used in this specification the term forge welding is intended to encompass all techniques which  
15 involve circumferential heating of pipe ends and subsequent metallurgical bonding the heated pipe ends, including welding techniques that are generally known as amorphous bonding, diffusion bonding, friction welding, flash butt welding and/or thermodynamic welding.

20 It is known from US patents 4,566,625; 4,736,084; 4,669,650 and 5,721,413 issued to Per H. Moe that it may be beneficial to flush the pipe ends just before and during the forge welding operation with a reducing flushing gas, such as hydrogen or carbon monoxide, such  
25 that any oxygen skin is removed from the heated pipe ends and a metallurgical bond with a minimal amount of irregularities is obtained. It is also known from US patents Nos. 2,719,207 and 4,728,760 to use non explosive mixtures comprising about 95% by volume of a

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substantially insert gas, such as argon, nitrogen and/or helium, and about 5% by volume of a reducing gas, such as hydrogen and/or carbon monoxide for flash welding and induction butt welding.

5 Experiments have shown that forge welding techniques are capable to generate high quality metallurgical bonds between tubular ends, in particular if the pipe ends are flushed with a reducing flush gas mixture during the heating and/or welding operation, but that the red-hot  
10 pipe ends are generally deformed such that upsets are formed in the region of the welding zone.

For many applications it is required to remove upsets after the welding operation, which then involves a grinding or machining operation which is difficult and  
15 expensive to accomplish at many sites where pipe ends are welded together, such as on oil rigs, pipe-laying barges and many offshore and onshore sites where underground or above ground pipelines are to be installed.

The method according to the preamble of claim 1 is known from US patent 4,669,650. In the known method the tubular ends are shaped in an inwardly sloping configuration. Japanese patent JP 03-243286 also discloses a forge welding method wherein the tubular ends have an inwardly sloping configuration. UK patent  
20 GB 793402 discloses a forge welding method wherein the welded pipe ends have complementary concave and convex shapes.

It is an object of the present invention to provide a method for forge welding of tubulars wherein the  
30 generation of upsets in the welding zone is minimized.

#### Summary of the Invention

The method according to the inventions comprises shaping the tubular ends that are to be welded together

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into a sloping configuration such that when the tubular ends are heated during the forge welding process the heated tubular ends deform as a result of thermal expansion into a substantially longitudinally oriented cylindrical shape, wherein the sloping angle of the inner and outer walls of the tubular ends is selected such that the ratio between the average diameter  $D(t)$  of the tip of the tubular end and the average diameter  $D(b)$  of the base of the tubular end is related to an estimated temperature difference between said tip and base of the tubular end during the forge welding process and a thermal expansion co-efficient of the steel grade or grades of the tubular end.

In addition the portion of each pipe that is to be forged may be reduced in cross section such that deformation during forging returns it to a dimension substantially the same as its original thickness.

The precise angles and dimensions of the end preparation depend on the material being joined and its coefficient(s) of expansion, wall thickness, pipe diameter, degree of heat required for welding, the width of the heated zone and the desired forge length. Typical values are provided in Table 1 below for carbon steel tubes approximately 4 mm wall thickness and 70 mm diameter.

The sloping angle of the inner and/or outer walls of the tubular ends may be selected such that the ratio between the average diameter  $D(t)$  of the tip of the tubular end and the average diameter  $D(b)$  of the base of the tubular end is related to an estimated temperature difference between said tip and base of the tubular end during the forge welding process and a thermal expansion co-efficient of the steel grade(s) of the tubular end.

For many forge welding operations said ratio  $D(t)/D(b)$  may be selected between 0.8 and 0.99.

To increase the surface of the forge welded pipe ends and to simultaneously assist alignment of the pipe ends the end face of one of the tubular ends that are to be welded together may have a substantially convex shape and the end face of the other tubular end may have a substantially concave shape.

The forge welded tubulars may comprise a low grade steel base pipe and a higher grade steel cladding on the inner and/or outer surface of the base pipe. In such case it is preferred that the end faces are shaped such that when the tubular ends are pressed together the end faces of the cladding(s) touch each other first the end faces of the base pipe ends subsequently touch each other. It is also preferred that any non-oxidising or reducing

flush gas is introduced from the opposite side of the pipe wall to the clad layer.

5 It will be understood that the inwardly tapered tubular end may have a large variety of shapes, and that the inward deflection may be determined by iterative calculation and/or experiments in order to assess that the amount of upset of the forge welded tubulars is reduced to a minimum.

10 In use the amount of material at the pipe ends deformed by forging is closely controlled to further minimise upset.

It is observed that US patent No. 4.669.650 discloses a forge welding process wherein the outer walls of the tubular ends are machined away to a greater depth than the inner walls of the tubular ends. The known configuration is, however, not configured such that the heated tubular ends are substantially cylindrical during the forge welding operation.

#### Description of preferred embodiments

20 Preferred embodiments of the method according to the present invention will be described with reference to the accompanying drawings, in which:

Fig. 1 shows a pair of concave and convex pipe ends that have been interconnected by the forge welding method according to the invention;

Fig. 2 shows how the concave and convex pipe ends are inwardly oriented at an inward sloping angle  $X$  which is selected such that the heated concave and convex pipe ends have a substantially longitudinal orientation;

30 Fig. 3 is a longitudinal sectional view of a pair of clad tubular ends just before they are joined by the forge welding method according to the invention;

Fig. 4a is a longitudinal sectional view of a pair of internally clad tubular ends wherein one tubular end is concave and the other tubular end is convex;

5 Fig. 4b is a longitudinal sectional view of a pair of externally clad tubular ends wherein one end is convex and the other end is concave; and

Fig. 5 is a longitudinal sectional view of an end of a clad tubular wherein the thickness of the clad layer is increased at the end of the tubular.

10 In Fig. 1, a pair of heated axially aligned pipe ends is shown and in Fig. 2 the unheated ends are shown, wherein X is the inward sloping angle, 1 = pipe having original wall thickness, 2 = minimum forge length required to complete the weld, 3,5,6 = typical radii of  
15 convex pipe end 9, 4 = first contact shoulder, 7 = pipe end having reduced wall thickness, 8 = pipe center line and 10 = concave pipe end. The sloping angles x of the unheated convex and concave pipe ends 9,10 illustrated in Fig. 1 are selected such that the heated pipe ends  
20 accurately intermesh and are accurately axially aligned as illustrated such that a seamless forge weld is created when the pipe ends 9 and 10 are pressed together and only minimal upsets are formed at the inner and outer surfaces of the pipes 1 in the region of the forge welded joint.

25 An outline of the dimensions of the pipe connection shown in Fig. 1 and 2 is described in Table 1:

Identifier (see Figure 1)	Description	Typical Value
X	Inward sloping angle	1 to 5°
1	Original wall thickness	4 mm
3, 5, 6	Preparation radii	0.6 mm
2	Minimum forge length	0.05 mm
7	Reduced wall thickness	3 mm
8	Pipe centre line	
4	First contact shoulder	

Table 1: Typical values for forge welding weld preparation - 4mm WT, 70 mm OD pipe

Referring now to Figure 3 there is shown an upper tubular 11 and a lower tubular 12 which each comprise a low grade steel base pipe have an inner cladding of high chromium steel 13.

5 The tubular ends 14 and 15 are wedge shaped such that the tips of the wedge shaped ends are formed by the claddings 13. This ensures that when the tubular ends are pressed against each other the claddings 13 touch each other before the ends of the base pipes touch each other.

10 Throughout the forge welding operation a flushing gas is flushed around the tubular ends 14 and 15 and to ensure continuation of the flushing between the tubular ends 14 and 15 after the claddings 13 touch each other, flushing gas is injected onto the uncladded outer

15 surfaces of the tubulars 11 and 12.

Figure 4a depicts an embodiment where the lower end surface 26 of the upper tubular 20 has a generally

concave shape and the upper end surface 23 of the lower tubular 21 has a generally convex shape.

5 The inner surface of the tubulars 20 and 21 is clad with a stainless steel lining 24 and 25 and the concave and convex end surfaces 23, 26 are shaped such that the linings 24 and 25 touch each other first and that the base pipes 20, 21 touch each other thereafter and that the unheated end surfaces 23, 26 are inwardly oriented at a sloping angle X. In this case a reducing  
10 non-explosive flushing gas is injected from the exterior of the tubulars and the tubular ends still form a wedge such that the touching zone gradually increases from the outer surface towards the inner surface of the forge welded tubulars. In this way a good bond between the  
15 linings 24, 25 is ensured and inclusion of oxides between the forge welded tubulars 20 and 21 is minimized.

Fig. 4b illustrates a forge welded joint of a pair of low grade steel base pipes 33, 34 of which the outer surface is clad with a stainless steel lining 30, 31  
20 and of which the end surfaces 35, 36 have an intermeshing convex and concave shape such that the unheated end surfaces 35, 36 are inwardly oriented at a sloping angle X and that the stainless steel linings 30, 31 touch each other before the base pipes 33, 34 touch each other  
25 when the end surfaces 35, 36 are heated and pressed together during the forge welding operation. In this case a reducing gas is injected from the interior side 44 of the tubulars during the forge welding operation.

Figure 5 depicts a tapered wedge shaped end 40 of a  
30 pipe 41 which has been clad with a clad layer 43 and where further material 42 compatible with the clad layer 43 has been deposited around the end of the pipe 2 to allow further machining without exposing the base



pipe 41. The inward sloping angle X of the tapered end 40 is selected such that the heated pipe ends are substantially axially aligned and the taper angle is selected such that the clad layers 43 of adjacent pipe ends touch each other first before the base pipes touch each other during a forge welding operation.